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NUCLEAR EXPLOSIONS - PEACEFUL APPLICATIONS

HEALTH AND SAFETY

September 1967

MAXIMUM MISSILE RANGES FROM SURFACE AND BURIED EXPLOSIONS

L. J. Vortman, 7111

SANDIA LABORATORIES

OPERATED FOR THE UNITED STATES ATOMIC ENERGY COMMISSION BY SANDIA CORPORATION | ALBUQUERQUE, NEW MEXICO; LIVERMORE, CALIFORNIA

Issued by Sandia Corporation,
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United States Atomic Energy Commission

Printed in the United States of America
Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U. S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy $3.00; Microfiche $0.65

TID-4500 (50th Ed.)
(UC-41, UC-35)
Nuclear Explosions -
Peaceful Applications
Health and Safety

SC-RR-67-616

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ABSTRACT

The ballistic boundaries, or maximum ranges of ejected material, for many applicable surface and buried explosions are summarized and scaling expressions are derived which will be helpful in predicting the ballistic boundaries for explosions of other energies. In establishing safety zones it is advisable to multiply predicted boundaries by a factor of 1.5 to 2.0, because of a finite probability that the boundaries observed for a limited number of events will be exceeded if more shots are fired.

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MAXIMUM MISSILE RANGES FROM SURFACE AND BURIED EXPLOSIONS

An estimate of maximum missile distances is needed for establishing safety criteria for cratering explosions. Ejecta formation and distribution involves complex mechanisms as indicated by the following outline:

Ground Shock:
- Initial velocity (particle velocity of the shock wave)
- Initial angle (position in the shock field)
- Missile size
  - Medium strength properties
  - Pre-existing fracture patterns
  - Shock strength

Modifying Phenomena:
- Acceleration due to gas expansion
- Acceleration by gas flow or air flow
- Acceleration or deceleration by friction with adjacent material
- Acceleration or deceleration and direction change by ballistic collision
- Deceleration by drag
- Local wind velocity (for small particles)

Theory

No general theory of ejecta formation and distribution exists. While Cherry (Reference 1) has a code which partially shows the dispersion for certain buried explosions, it neglects missile size and all of the modifying phenomena.

Sherwood (Reference 2) has treated air drag by adopting a ballistic trajectory after the acceleration due to gas expansion has ceased. He also adopts an experimentally obtained particle-size distribution. He does not take into account this particle-size spatial distribution within the stress field: the smallest particles originate closest to the charge where stress levels are high and where at certain locations initial velocities are high. Still, his work is a considerable refinement on that of Cherry, and of Hess and Nordyke (Reference 3).

Any further development of Sherwood's approach would be better suited to determining ejecta distribution than to defining a ballistic boundary. The maximum missile range is a probabilistic matter relating to medium properties and the particle-size spatial distribution mentioned above. Using Sherwood's model, it is possible to determine the maximum range for any given particle size; it is not possible to determine the probability that a missile of a size which maximizes range will also originate from a point which maximizes range.

Bishop (Reference 4) treated the simpler situation of the ballistic boundary from cased explosive charges detonated above ground, based on early work by Gurney (Reference 5). Their methods if applied to surface bursts or buried uncased charges would result in overestimates of maximum missile ranges.

Absence of a theory for predicting a ballistic boundary makes it necessary to fall back on experimental determination of that boundary.

Results of Experiment

Tables I-IV summarize the available data on ballistic boundaries without regard for missile size. The tables cover the boundaries for missiles from spherical charges on and in soil and rock, and for hemispherical charges on soil and rock. It should be emphasized that the ranges given were the maximums observed, but it is quite possible that missiles at greater ranges escaped detection. Consequently maximum range in the sense used here should be interpreted as meaning "at least as far as."

Surface Bursts

Figure 1 shows surface burst data together with scaling relationships developed (Henny and Carlson, Reference 6). The power law for the ballistic boundary for missiles from hemispherical charges on soil parallels the one for hemispherical charges on rock, but its value is about 45 percent of that for rock. In spite of the poorer shock transmission in soil, the shock strengths are sufficient to break the soil into smaller pieces of ejecta which have a more drag-limited trajectory.

The White Tribe boundary is nearly twice that for the SES events (Table IV), either because the caliche tends to form clods which have a greater range or because the charge was one of three detonated simultaneously in a triangular array which may have resulted in an enhanced trajectory.

For spherical charges, the results of the MTCE events yield power laws quite different from those of hemispherical charges (Tables I and III). There is no clear reason why a ballistic boundary from spherical charges should scale differently. It is a judgment that the boundary for the 2000 and 4000-pound spherical charges is too small, either because maximum trajectory missiles were not produced or because, if produced, they were not found. It is also believed that a better description of the ballistic boundary would be given by a power law of

approximately $W^{0.4}$ applied to the maximum range for the 16,000-pound MTCE and the Flat Top I events. This suggests nearly twice the maximum range for spherical charges as for hemispherical.

The 2425-, 3325-, and 3286-foot ranges for the Air Vent I, and Flat Top II and III spherical charges (Table II) are for plastic artificial missiles. They probably represent typical boundaries for soil containing rocks of comparable size.

Buried Charges

Observed ballistic boundaries for buried spherical charges are also tabulated in Tables I and II. Attempts to scale the ballistic boundary by cube-root scaling made it clear that cube-root scaling was not applicable. Trials with other scaling values indicated that the most consistent results could be obtained by scaling the depth of burst (DOB) by $W^{1/3}$ and the maximum ballistic range by $W^{1/6}$. The upper boundary of the DOB/range relationship is in the rock data of Buckboard, Pre-Schooner, Pre-Schooner II, and Palanquin. The Sulky maximum range is low because it was obtained from aerial photographs rather than ground-level observation. For Dugout, a row charge, both the weight of a single charge and of the total row are indicated. If scaled as a single 40,000-pound charge, Dugout is in reasonable agreement with the other rock data (see Figure 2). Palanquin is also shown twice in Figure 2, both for the announced yield and for half that value; the lower yield was indicated by air-blast data (Reference 27).

The maximum values for soil are always less than those for rock because the soil breaks into less than optimum trajectory sizes, the stress wave is weaker, and what stones there are in the soil may not be of a size and location for maximum trajectory. In principle the ballistic boundary for stones included in soil could nearly equal that for rock if a stone of the proper size existed in an appropriate location. The probability is low, however. Maxima from Sedan and from CAPSA 8 approach rock values but the plastic artificial missile of Air Vent I did not do so, and in the same shot, natural missiles were observed only to 1800 feet.

Max range soil-hemisphere $= 14.8\,W^{.39} \approx Z\,W^{.4}$

$Z = 13.19$ for $W = 10^5$

Conclusions

Surface Explosions: (10^3 lb to 10^6 lb)

	Rock	Soil
Hemispheres	$R_{max} = 30W^{0.4}$	$R_{max} = 13\,W^{0.4}$
Spheres	$R_{max} = 70W^{0.4}$	$R_{max} = 30\,W^{0.4}$

Buried Explosions: (10^3 lb to 0.5 kt)

$$R_{max} = W^{1/6}\left[-533\left(\frac{DOB}{W^{1/3}}\right)^3 + 2307\left(\frac{DOB}{W^{1/3}}\right)^2 - 3678\left(\frac{DOB}{W^{1/3}}\right) + 2407\right].$$

There is a finite probability that boundaries arrived at on the basis of a small sample would be exceeded by a larger number of events. Where the above relationships are used for safety considerations, it is advisable that the maximum ranges be multiplied by 1.5 or 2.

There is a paradox in that the maximum ranges for surface bursts scale as $W^{0.4}$ whereas those for buried charges appear to scale as $W^{1/6}$. There is a similar paradox related to scaling of crater radius; surface bursts scale as $W^{0.4}$ and buried charges as $W^{1/4-1/3}$. Since we are unable to explain either, it would not be surprising if both paradoxes were found to have a common cause. Both leave an uncertainty about which scaling is proper for shallow buried charges. Thus, in the region between zero and $\frac{DOB}{W^{1/3}} = 0.4$ ft/lb$^{1/3}$, it is recommended that the surface burst predictions be applied.

for 10^5 lb: $\dfrac{\text{MAX RANGE Soil-Hemisphere}}{\text{MAX RANGE Rock-Hemisphere}} = \dfrac{14.8(10^5)^{.39}}{30.2(10^5)^{.40}} = .4368$

Assuming: $\dfrac{\text{MAX Range Soil-sphere}}{\text{MAX Range Rock-sphere}} \approx .4368$ Also, then:

MAX Range Soil-sphere $\approx .4368(70W^{0.4}) = 30.58W^{0.4}$

for Rock: $\dfrac{\text{MAX Range Spheres}}{\text{MAX Range Hemispheres}} = \dfrac{70W^{0.4}}{30W^{0.4}} = \dfrac{7}{3}$

Assuming for soil: $\dfrac{\text{MAX Range Spheres}}{\text{MAX Range Hemispheres}} \approx \dfrac{7}{3}$ also, then: MAX Range Spheres $\approx 14.8\left(\frac{7}{3}\right)W^{0.39}$ $= 34.53\,W^{.39}$ BUT $34.53(10^5)^{.39} = Z(10^5)^{.40}$ $Z = 30.78$ $\therefore$ can use $30.78\,W^{0.4}$

TABLE I

Spherical Charges - Rock Medium

Series-Shot	Charge Weight	Burial Depth (ft)	Maximum Range (ft)	Medium	Ref
MTCE - ST1	4,000 lb	2.2 above	250	Basalt	6
- ST3a	4,000 lb	2.2 above	180	Basalt	6
- S2a	4,000 lb	0	850	Basalt	6
- S4a	4,000 lb	0	720	Basalt	6
- C2	4,000 lb	2.2	3,300	Basalt	6
- CS	2,000 lb	0	450	Basalt	6
- LS	16,000 lb	0	3,225	Basalt	6
Flat Top I	40,000 lb	0	4,060	Limestone	7
Buckboard 11	40,000 lb	25.5	4,158	Basalt	8
Buckboard 12	40,000 lb	42.7	1,988	Basalt	8
Buckboard 13	40,000 lb	58.8	No Record	Basalt	8
Buckboard 5, 10	1,000 lb	5	3,300	Basalt	8
Buckboard 4	1,000 lb	10	1,650	Basalt	8
Buckboard 8	1,000 lb	15	870	Basalt	8
Pre-Schooner A	39,250 lb	59	507	Basalt	9
B	39,450 lb	51	984	Basalt	9
C	39,840 lb	67	216	Basalt	9
D	39,590 lb	43	1,550	Basalt	9
Pre-Schooner II	180,000 lb	71	2,320	Basalt	10
Dugout	5x40,000 lb (Row)	59	1,279	Basalt	11
Palanquin	4.3 kt	280	1,590	Basalt	12
Danny Boy	0.43 kt	110	> 879	Basalt	13
Sulky	0.085 kt	90	> 87	Basalt	14

TABLE II

Spherical Charges - Soil

Series-Shot	Charge Weight	Burial Depth (ft)	Maximum Range (ft)	Medium	Ref
Sedan	100 kt	635	7,019	NTS alluvium	15
CAPSA 8	1,000 lb	12.5	970	Albuquerque alluvium	16
Stagecoach 1	40,000 lb	80	No Record	NTS alluvium	17
Stagecoach 2	40,000 lb	17.1	510	NTS alluvium	17
Stagecoach 3	40,000 lb	34.2	1,793	NTS alluvium	17
Scooter	1,000,000 lb	100	No Record	NTS alluvium	18
Dugway 310	320 lb	3.5 above	250	Dry clay	19
Dugway 312	2,560 lb	7	500	Dry clay	19
Dugway 315	40,000 lb	17.5	1,050	Dry clay	19
Dugway 318	320,000 lb	35	3,500	Dry clay	19
Air Vent I	40,000 lb	17.1	1,800/ 2,425*	Playa	20
Jangle HE 3	2,560 lb	6.84	3,500	NTS alluvium	21
Jangle U	1.2 kt	17	5,500	NTS alluvium	22
Flat Top II	40,000 lb	0	3,325*	Playa	20
Flat Top III	40,000 lb	0	3,286*	Playa	20

*Plastic artificial missile

TABLE III

Hemispherical Charges - Rock

Series-Shot	Charge Weight (lb)	Burial Depth (ft)	Maximum Range (ft)	Medium	Ref
MTCE H1	4,000	0	780	Basalt	5
MTCE H2	16,000	0	1,500	Basalt	5
Sailor Hat	1,000,000	0	7,200	Basalt	23

TABLE IV

Hemispherical Charges - Soil

Series-Shot	Charge Weight (lb)	Burial Depth (ft)	Maximum Range (ft)	Medium	Ref
White Tribe	11,560	0	1,100	Caliche	24
SES- Snowball	1,000,000	0	3,250	Silt	25
SES	200,000	0	1,850	Silt	26
SES	10,000	0	540	Silt	26

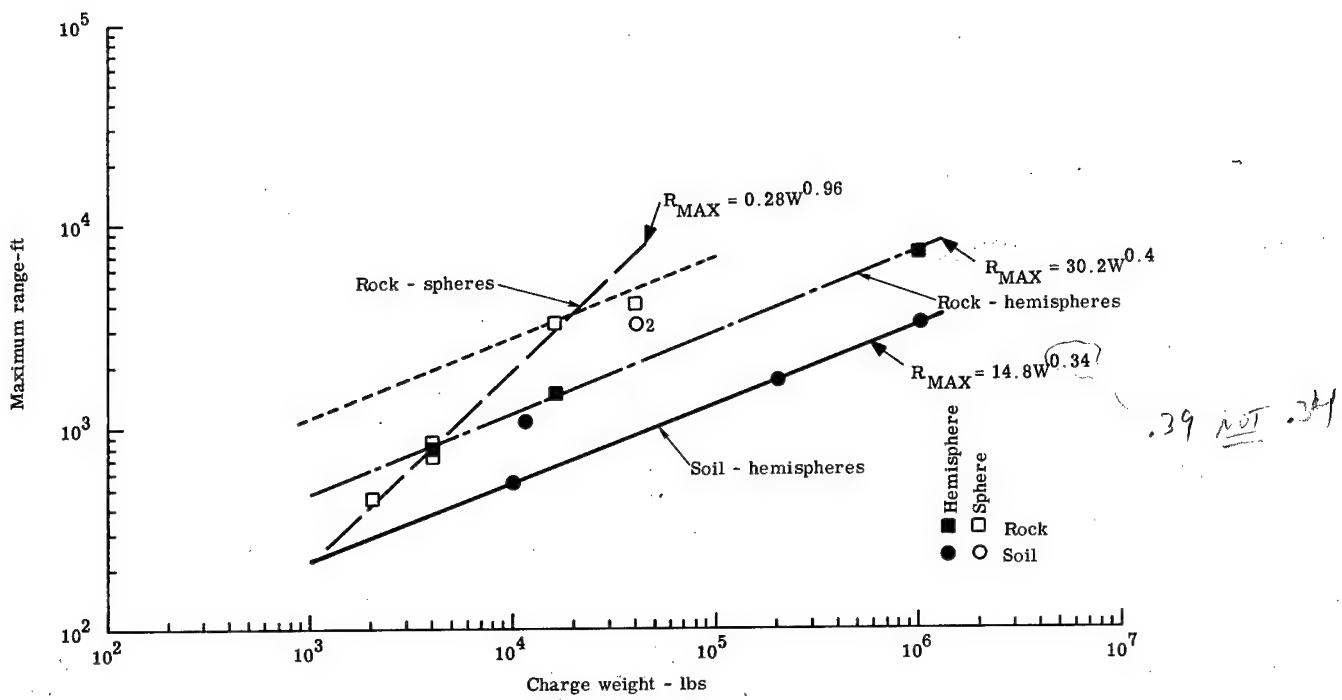

Figure 1. Surface burst scaling relationships (Data for rock from Reference 6)

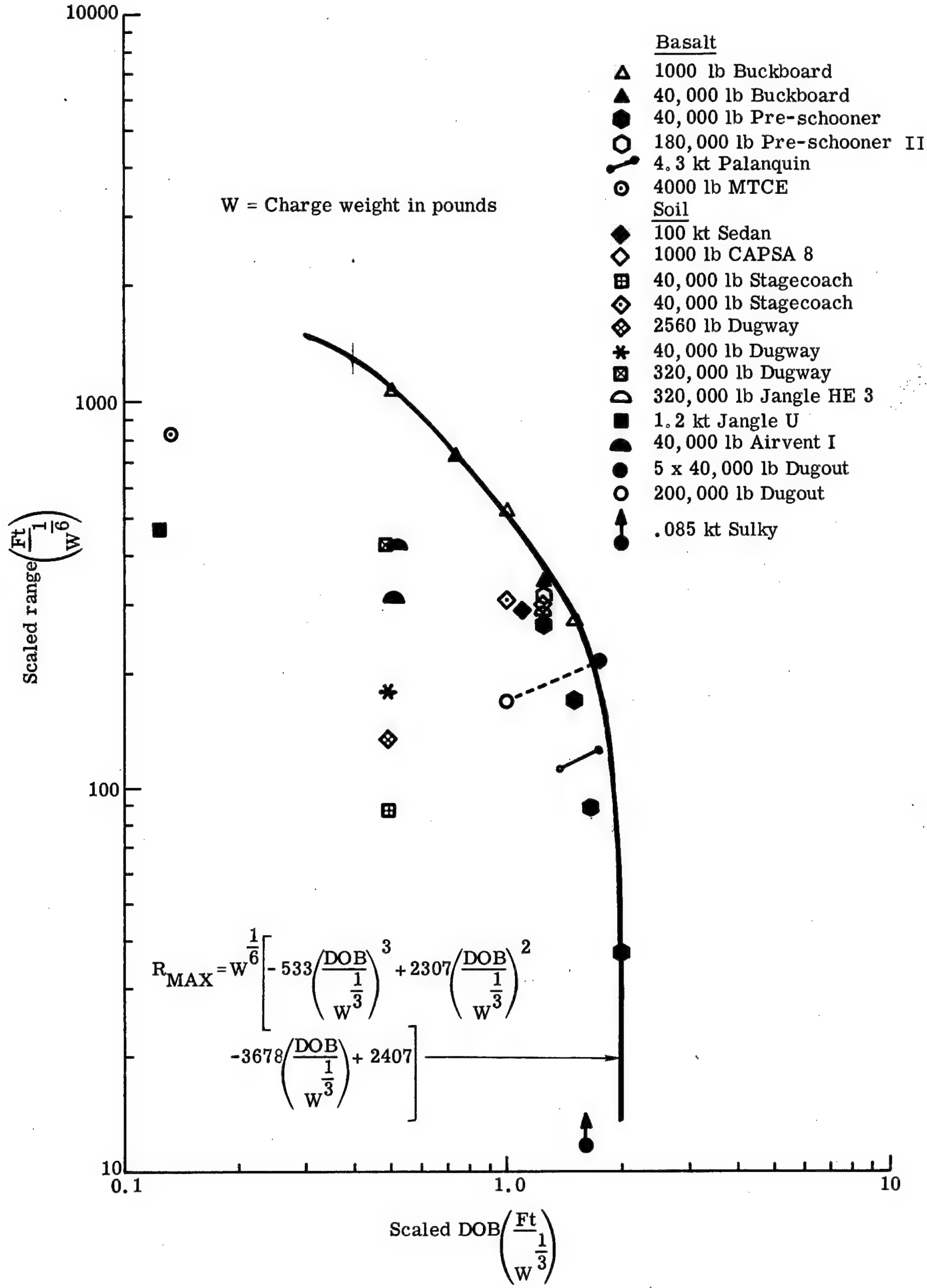

Figure 2. Buried charges scaling relationships

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